Applied Thermal Engineering 58 (2013) 336–343

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Experimental performance comparison of shell-and-tube oil coolers with overlapped helical baffles and segmental baffles

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HIGHLIGHTS

- The performance of OCHB and OCSB with practical size is experimentally investigated.
- The shell side heat transfer coefficients of the OCHB are lower than that of the OCSB.
- The shell-side pressure drop of the OCHB is far lower than that of the OCSB.
- The OCHB obtains higher heat transfer coefficient per unit pressure drop.
- With proper design OCHB can obtain better heat transfer performance.

ARTICLE INFO

Article history:
Received 20 December 2012
Accepted 8 April 2013
Available online 28 April 2013

Keywords:
Oil cooler
Helical baffle
Segmental baffle
Pressure drop
Heat transfer

ABSTRACT

Many research studies have been conducted on the performance of shell and tube heat exchanger with helical baffles because of its lower shell-side pressure drop, lower fouling resistance and lower operation and maintenance cost. But the extension of those studies into practical application is limited because of the additional effects caused by the small-size model. In this paper, the performance of shell-and-tube oil coolers with overlapped helical baffles and segmental baffles is compared experimentally, and both of the oil coolers are practical products. The results show that the OCHB (Oil Cooler with Helical Baffles) gets lower shell side pressure drop and higher heat transfer coefficient per unit pressure drop at fixed volume flow rate than the OCSB (Oil Cooler with Segmental Baffles). Based on the experimental data, it can be predicted that with proper design the OCHB can get better heat transfer performance than OCSB. The present studies are beneficial for the design and practical operation of OCSB and OCHB.

1. Introduction

More than 35–40% of heat exchangers used in industrial areas are of the shell-and-tube heat exchangers (STHXs) due to their robust geometry construction, easy maintenance and possible upgrades [1]. The shell and tube oil cooler is widely used in the chemical engineering process and machining process, which maintains an oil (e.g. lubricating oil, conductive oil) supply at a consistent, optimal temperature. In STHXs, the shape and arrangement of baffles are of essential importance for the performance of heat exchangers. The most commonly used baffle is the segmental baffle, which forces the shell-side fluid to go through in a zigzag manner. But there are three major drawbacks in the conventional shell-and-tube heat exchangers with segmental baffles (STHXsSB): (1) it causes a large shell-side pressure drop; (2) it results in a dead zone in each compartment between two adjacent segmental baffles, leading to an increase of fouling resistance; (3) the dramatic zigzag flow pattern also causes high risk of vibration failure on tube bundle.

To overcome the above-mentioned drawbacks of the conventional segmental baffle, a number of improvements were proposed to obtain higher heat transfer coefficient, lower possibility of tube vibration, and reduced fouling factor [2–7]. But the principal shortcomings of the conventional segmental baffle still remain. In the 1990s, a new type of baffle called helical baffle was first proposed by Lutcha and Nemcansky [8] and then further studied by Stehlik et al. [9] and Kral et al. [10]. For the convenience of manufacturing, most helical baffles actually used in STHXs are noncontinuous approximate helicoids. The noncontinuous helical baffles are usually made by four elliptical sector-shaped plates, as

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http://dx.doi.org/10.1016/j.applthermaleng.2013.04.009

shown in Fig. 1, where the helix angle, designated by β, helical pitch, B, and baffle thickness, S_p, are presented. Each baffle occupies one-quarter of the cross section of the heat exchanger and is angled to the axis of the heat exchanger. The two adjacent baffles may be joined end to end at the perimeter of each sector, forming a continuous helix at the outer periphery (Fig. 2). Another connection between two adjacent sectors is the overlapped connection, usually middle-overlapped as shown in Fig. 1. For heat exchangers with large shell diameters, the overlapped structures can reduce the helical pitch to shorten the length of heat exchanger and can also reduce the cross-flow area to obtain higher shell-side velocity. Therefore such connection is more popular in engineering practice. The OCHB tested in this paper is of this type (but not middle overlapped).

Many research studies have been done on the shell-and-tube heat exchangers with helical baffles (STHXsHB). Typical experiment studies of this subject since the year of 2000 are listed in Refs. [11–16]. Typical progresses in simulations of STHXsHB can be found in Refs. [17–25]. It should be noted that the rapid development of CFD commercial code and computer hardware helps the direct 3D numerical simulation of complex flow phenomenon in STHXsHB and it is becoming more and more convenient and popular.

Apart from the above studies, further improvement on the structure of shell and tube heat exchanger with non-continuous helical baffles has been proposed to overcome the shortcut flow in the shell side of shell-and-tube heat exchangers with non-continuous helical baffles. Wang and his co-workers proposed shell-and-tube heat exchangers with continuous helical baffles, shell-and-tube heat exchangers with combined helical baffles and combined multiple shell-pass shell-and-tube heat exchangers with continuous helical baffles [26–33]. Ji et al. [34] invented a double shell-pass shell-and-tube heat exchanger with continuous helical baffles (STHXCH) to improve the shell-side performance of STHXCH. Chen et al. [35] proposed a novel helical heat exchanger structure consisting of circumferential-overlap trisection helical baffle and numerically investigated the flow and heat transfer characteristic of the heat exchanger.

The geometries of STHXsHB being tested in above-mentioned experimental studies are listed in Table 1. From Table 1 it could be found that the most of the heat exchangers in those studies are small-size models and the sizes of most of the heat exchangers are smaller than 200 mm × 1000 mm (Inner diameter of the shell × Effective length). The spread of test results obtained in those studies in the design and operation of practical products might be limited due to the additional effects caused by models. In this paper, the performance of shell-and-tube oil coolers with overlapped helical baffles and segmental baffles is compared experimentally.

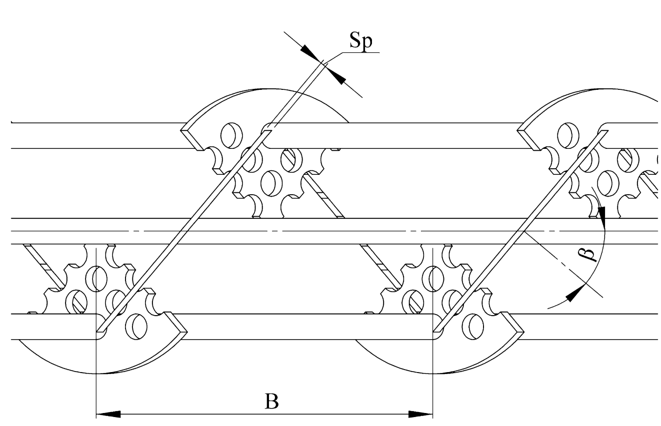

Fig. 1. Schematics of four pieces middle-overlapped helical baffle arrangement and parameters definition.

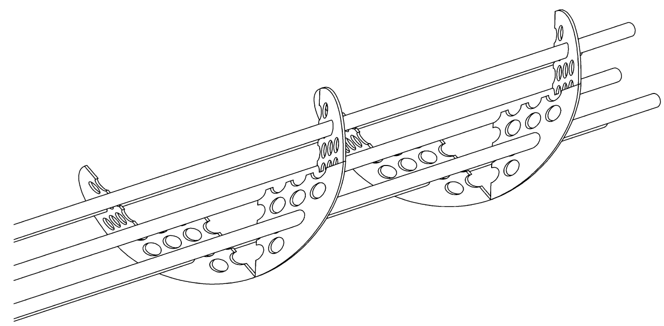

Fig. 2. Four pieces middle-overlapped helical baffle arrangement.

Table 1
Geometries of the STHXsHB in open experimental studies.

Researchers	Inner diameter of the shell/mm	Effective length/mm
Zhang et al. [12]	139.8	714
Zhang et al. [15]	110	750
Liu et al. [16]	51	195
Wang et al. [26]	207	620
Peng et al. [27]	207	620
Wang et al. [29]	210	1598
Chen et al. [33]	207	620

And both of the oil coolers are practical products. The results are beneficial for the design and practical operation of OCSB and OCHB. And reliable experimental data is also useful for numerical method validation. Finally suggestions on the performance improvement of OCHB are given.

2. Experiment system and method

The geometry parameters of the OCSB and OCHB are listed in Tables 2 and 3, respectively. The details of experiment system and experimental method can be found in Ref. [14]. The schematic of the experiment system is shown in Fig. 3. For the readers' convenience, brief introduction on the experiment system and experiment method is supplied. The conductive-320 oil is used as the shell-side heat transfer medium. The oil is driven by a pump to conduct the heat exchange process. The oil is heated by an adjustable electric heater. The volume flow rate of oil can be adjusted by the electrically operated valve. For the water cycle, the cooling water is pumped into the system from the water tank, and passes through the tube side of the heat exchanger. After that, the heated water is cooled down by the air cooling tower and returns to the water tank for re-usage. The volume flow rate of water is also

Table 2
Geometry of the OCSB.

Item		Dimensions and description
Shell side parameters	D_o/D_i/mm	325/309
	Material	Stainless steel
Tube parameters	d_o/d_i/mm	10/8
	Effective length/mm	2385
	Number	440
	Layout pattern	30°
	Tube pitch/mm	13
	Material	Stainless steel
	Tube pass	2
Baffle parameters	Cut ratio	25%
	Thickness/mm	2.5
	Number	19
	Baffle pitch/mm	110